Environmental Effect on Naval Warfare Simulations

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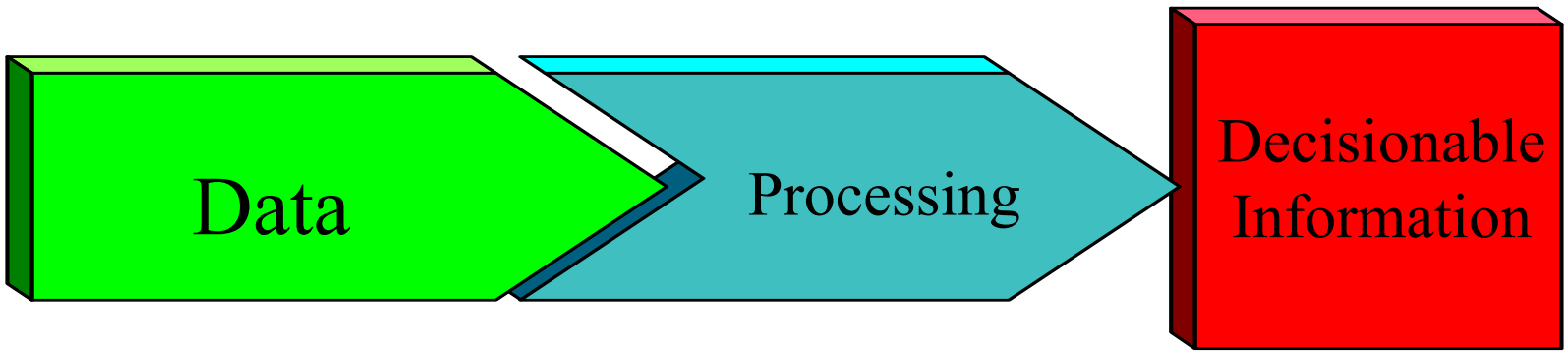
Premises

- 1. The Revolution in Military Affairs (RMA) has created a need for change both conceptually and in the processes by which METOC products and services are provided.
- 2. Quantitative methods are available to help assess this need for change.
- 3. METOC process engineering should consider quantitative results.

The Need for Change

- Incremental improvements do not reflect the RMA.
- Warfighters got “what we could give” not “what improved operational effectiveness.”

METOC Today



Remote sensing
In-situ measures
Climatology

METOC Models

Gridded Fields

- Placing gridded data fields into the warfighters' applications software is as far as we go it terms of fully automated METOC information flow.

A New Way to Look at METOC

- Warfighter defines the context
  - Knowledge-Based Warfare (KBW)
- "Value-added" is redefined using "Value-Focused Thinking"
- Knowledge producer becomes responsible for the total process of information flow and employment.

Knowledge-Based Warfare (KBW)

- From the First Secretary of Defense Strategic Studies Group
  - "to investigate the opportunities and requirements generated by a full adoption of a precision strike regime and to develop a strategy for implementing the transition to such a regime."

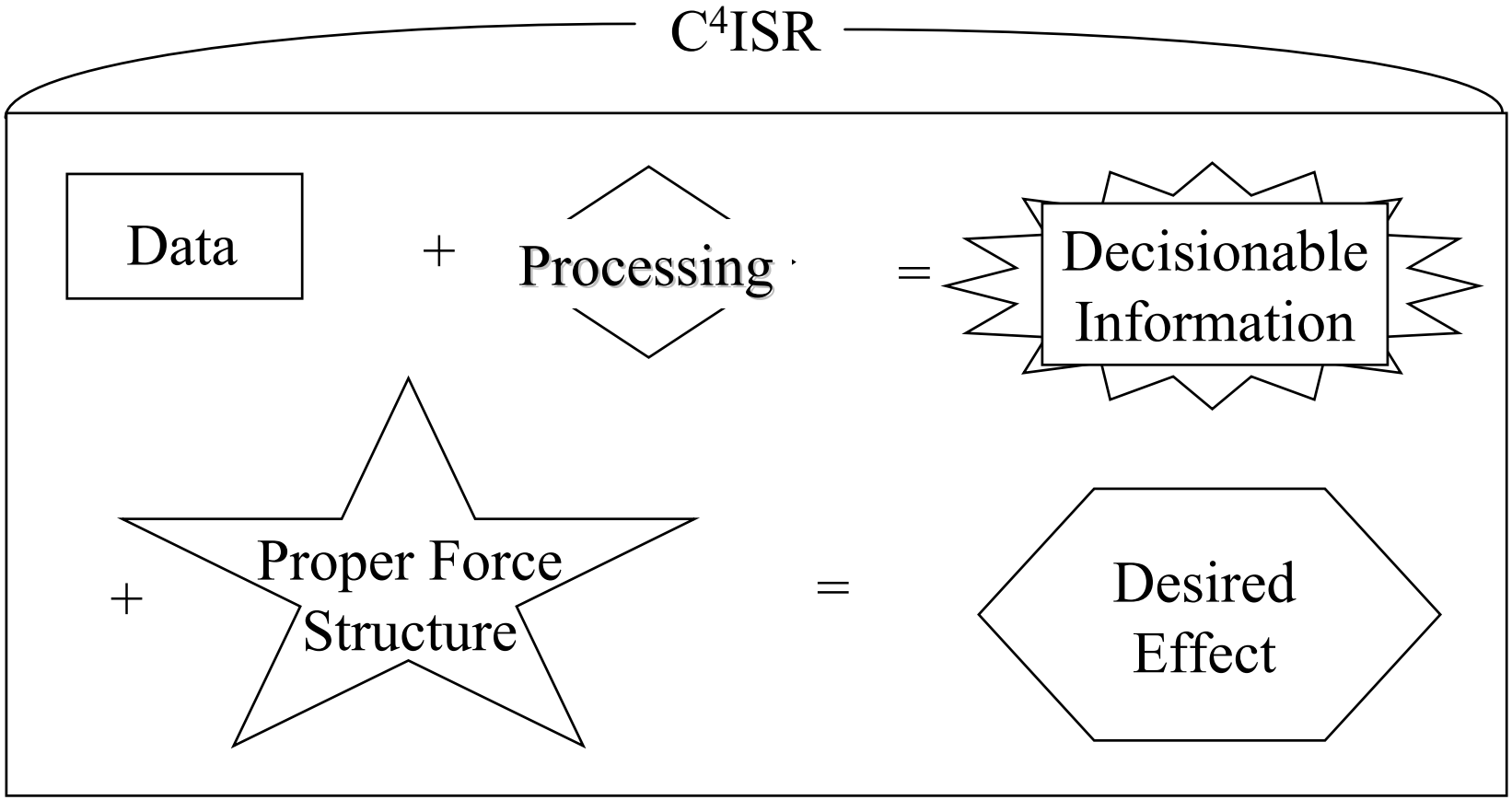
KBW Conceptual Process (1)

- 1. Data from all available sources
- 2. Computer processing power [Modeling, Simulation, Tactical Decision Aids (TDAs)]
- 3. Decisionable Information is information delivered to the right person at the right time in a useable format

KWB Conceptual Process (2)

- 4. Properly equipped and constituted force structure focused on a clearly understood strategic outcome
- 5. Assess the result of measures and ensure the validity of the desired effects through constant monitoring and feedback
- 6. C^4ISR = A robust C^4 system coupled with an accurate and high fidelity intelligence and reconnaissance system

KBW Process


C4ISR
Data
+
Processing
=
Decisionable Information
+
Proper Force Structure
=
Desired Effect

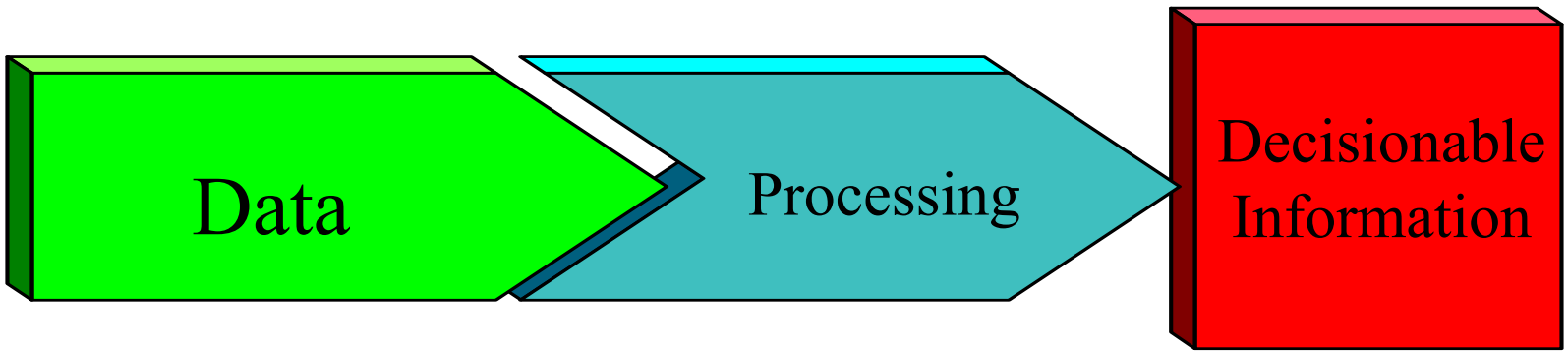
KBW Process Engineering

- "To help combat forces an integrated C^4ISR system must produce decisionable information. This calls for a deliberate process engineering effort to determine what information is needed by whom, when, and in what format." Casper et al.(1996)

METOC Knowledge Producer Responsibilities

- determine when, how, and to whom data has an operationally effective value.
- determine how long it takes to become decisionable information.
  - "A more complete measurement of timeliness issues would consider the time required by operators to develop knowledge from data and act on it." Strickland (1996)
- determine how long it will remain useful (and replace it when it is no longer useful).

METOC for KBW



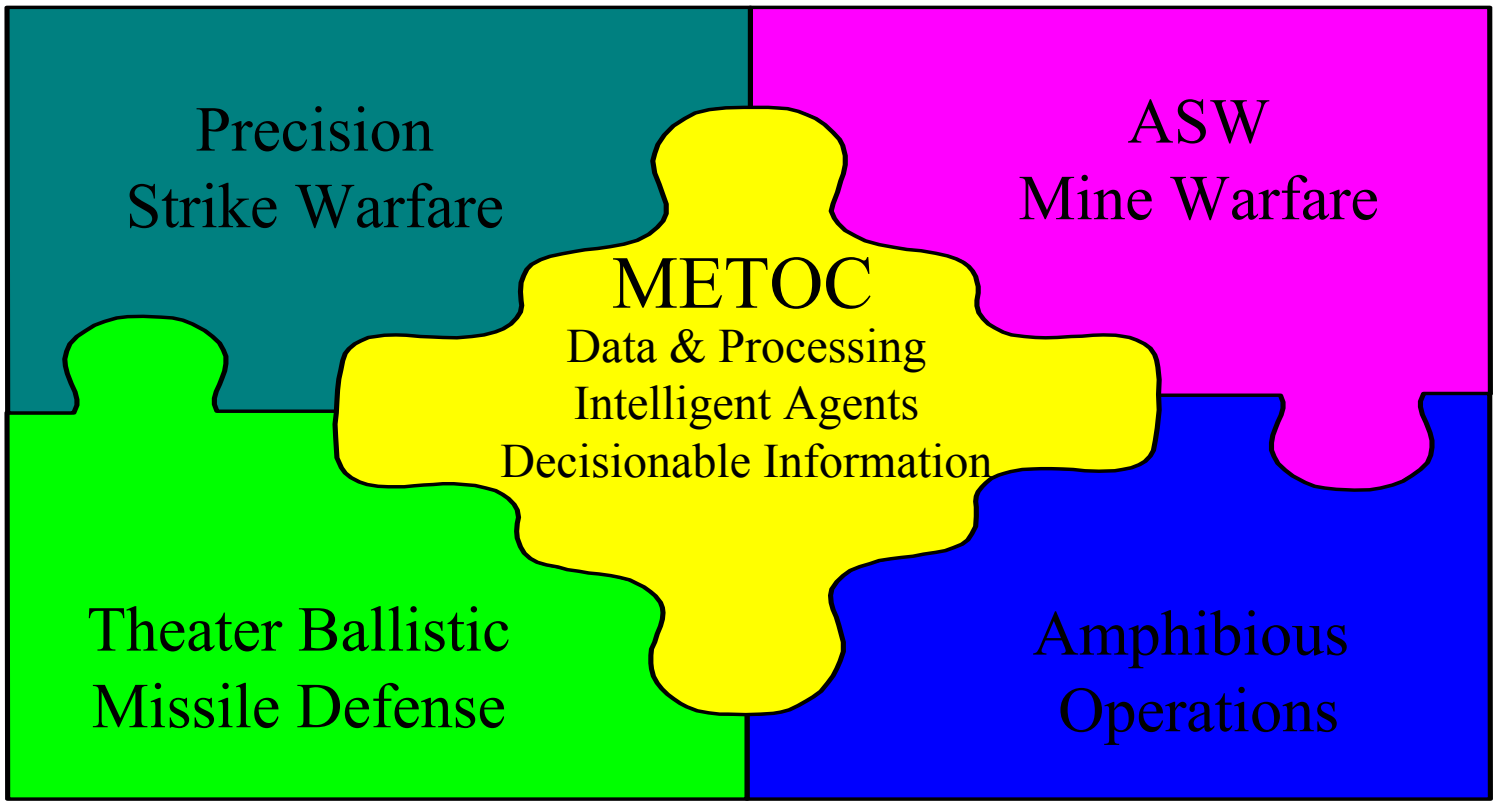
Remote sensing
In-situ measures
Climatology
Model Outputs

Tactical Decision Aids
Warfare Simulations
Fire Control Software

Optimum weapon/ platform mix & Sensor settings

- A more complete measure of METOC value added will include the time required by operators to develop knowledge from data and act on it.

Knowledge based METOC



Environmental Effect on Military Operations

- Military Operations :
  - Type: mine warfare, ASW, precision striking warfare, amphibious warfare, …
  - Scales: theater-level, fleet, tactical ...
- METOC:
  - Parameters: temperature, salinity, sound speed, velocity, waves, tides, sediment, …
  - Scales: spatial and temporal

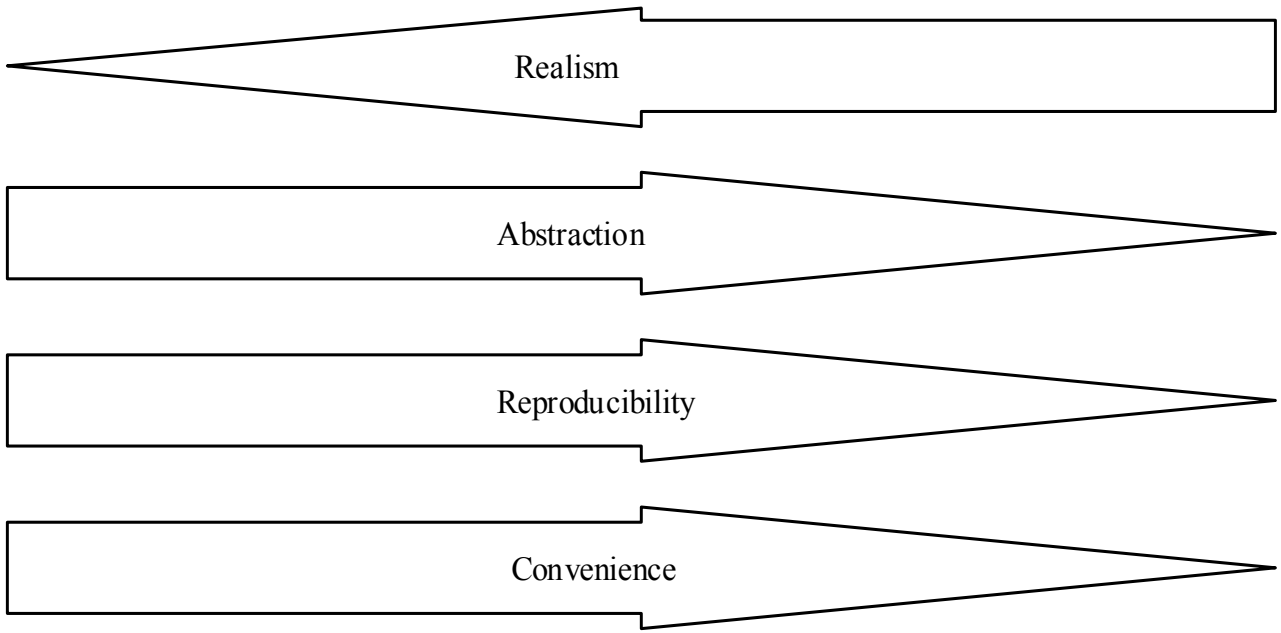
Weather Factors (Dupuy, 1990)

Weather Characteristics	Mobility	Attack	Artillery	Air	Tanks	Casualties
Dry - Sunshine – Extreme Heat	0.9	1.0	1.0	1.0	0.9	0.8
Dry - Sunshine – Temperate	1.0	1.0	1.0	1.0	1.0	1.0
Dry - Sunshine – Extreme Cold	0.9	0.9	0.9	1.0	0.9	0.7
Dry - Overcast – Extreme Heat	1.0	1.0	1.0	0.7	1.0	0.9
Dry - Overcast – Temperate	1.0	1.0	1.0	0.7	1.0	1.0
Dry - Overcast – Extreme Cold	0.9	0.9	0.9	0.7	0.8	0.6
Wet - Light - Extreme Heat	0.9	0.9	0.9	0.5	0.7	0.7
Wet - Light - Temperate	0.8	0.9	1.0	0.5	0.7	0.7
Wet - Light - Extreme Cold	0.8	0.9	1.0	0.5	0.7	0.4
Wet - Heavy - Extreme Heat	0.5	0.6	0.9	0.2	0.6	0.5
Wet - Heavy – Temperate	0.6	0.7	0.9	0.2	0.5	0.5
Wet - Heavy - Extreme Cold	0.5	0.6	0.8	0.2	0.5	0.3

The Model Spectrum and Characteristic Trends adapted from Hughes (1989)

Fleet Exercises - Manual War Games - Computer Assisted Games - Mathematical Analysis

Seas/Weather - Customized Scenario - Historic Gridded Field Data - Climatology - Mathematical Models



METOC Horizontal Scales

- Turbulent microscale [mm]
- Turbulent macroscale [O(h/10)]
- Frontal scales [0.1 to 1 km]
- Dynamic (eddy) mesoscale [$O(R_d)$]*
- Topographic scale [O(kms) to L]
- Basin scale [$L = O(10^3 H)$]
- Atmospheric mesoscale [3 to 300 km]
- Atmospheric Synoptic [300 to 3000 km]

METOC Vertical Scales

- Turbulent microscale [mm]
- Turbulent macroscale [uncertain]
- Mixed layer depth [h]
- Permanent thermocline [O(H/10)]
- Topographic scale [≤H]
- Total water depth [$H = O(10^2\ h)$]
- Atmospheric column [10 km]

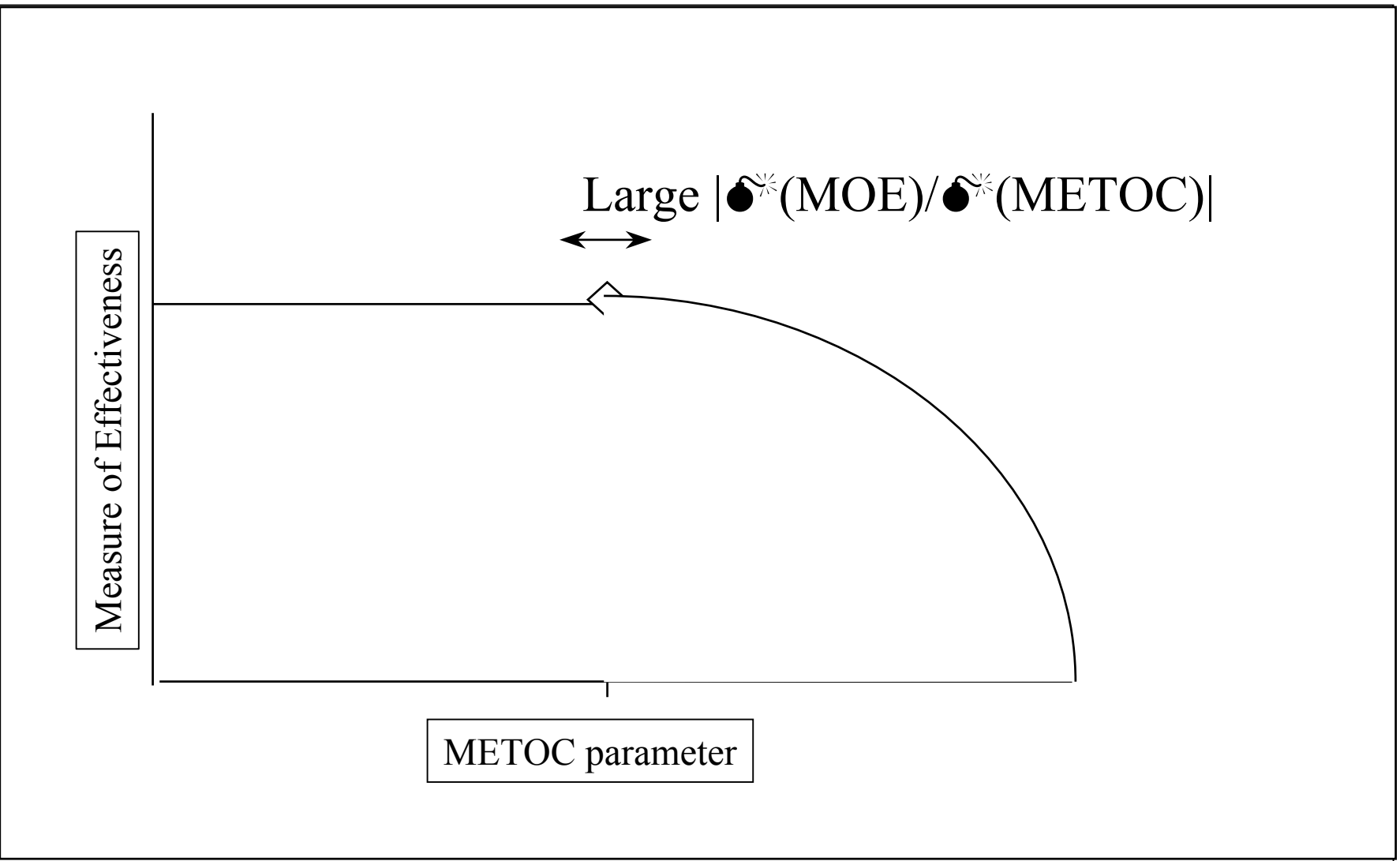
METOC Temporal Scales

- Turbulent turnaround times: sec - min
- Surface gravity waves: 1-10 sec
- Inertial waves: hrs
- Diurnal variation: 1 day
- Front: days
- Eddy: weeks
- Seasonal Variations: months

Effect of METOC on Military MOEs

- What is the effect on MOEs of varying METOC parameters in established M&S environments?
- What can this tell us about required METOC data input speed and accuracy for a given warfare area and doctrine?

Large Effect of METOC on MOE



Measures of Effectiveness

- When does a decrease / increase in accuracy or resolution cause a corresponding decrease / increase in a measure of operational effectiveness.

M&S on Various Scales

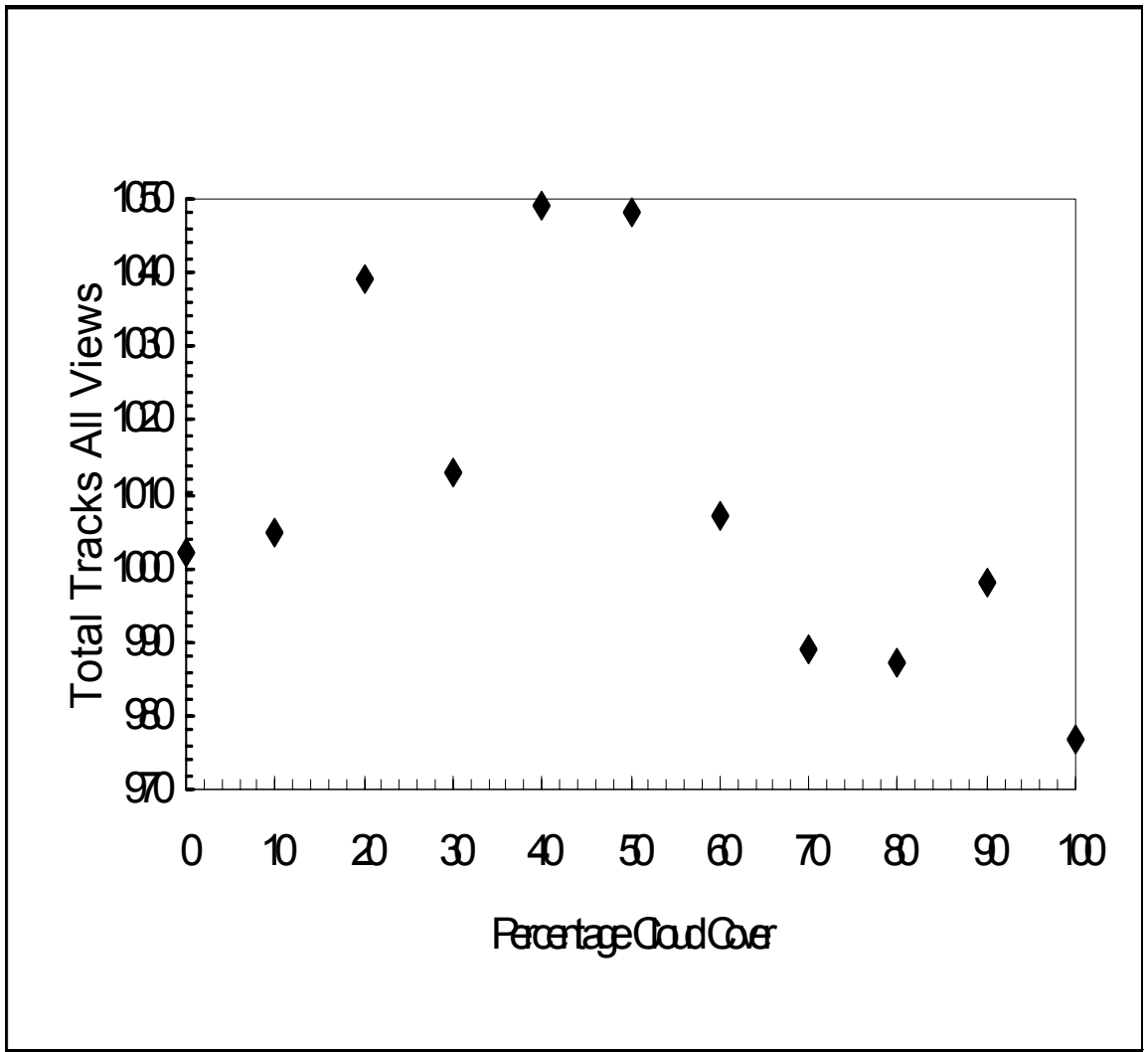
- Theater Level Scale:
  - RESA, JTLS, JSIMS, JWARS, …
- Tactical Scale:
  - Mine countermeasure
  - Mine impact burial prediction ...

RESA Weather Input

Variable	Units
region	number
wave height	feet
direction	degrees
wind speed	knots
direction	degrees
cloud cover	percent
ceiling	feet
depth	feet
visibility	nautical-miles
category	CLEAR | HAZE | FOG | RAIN

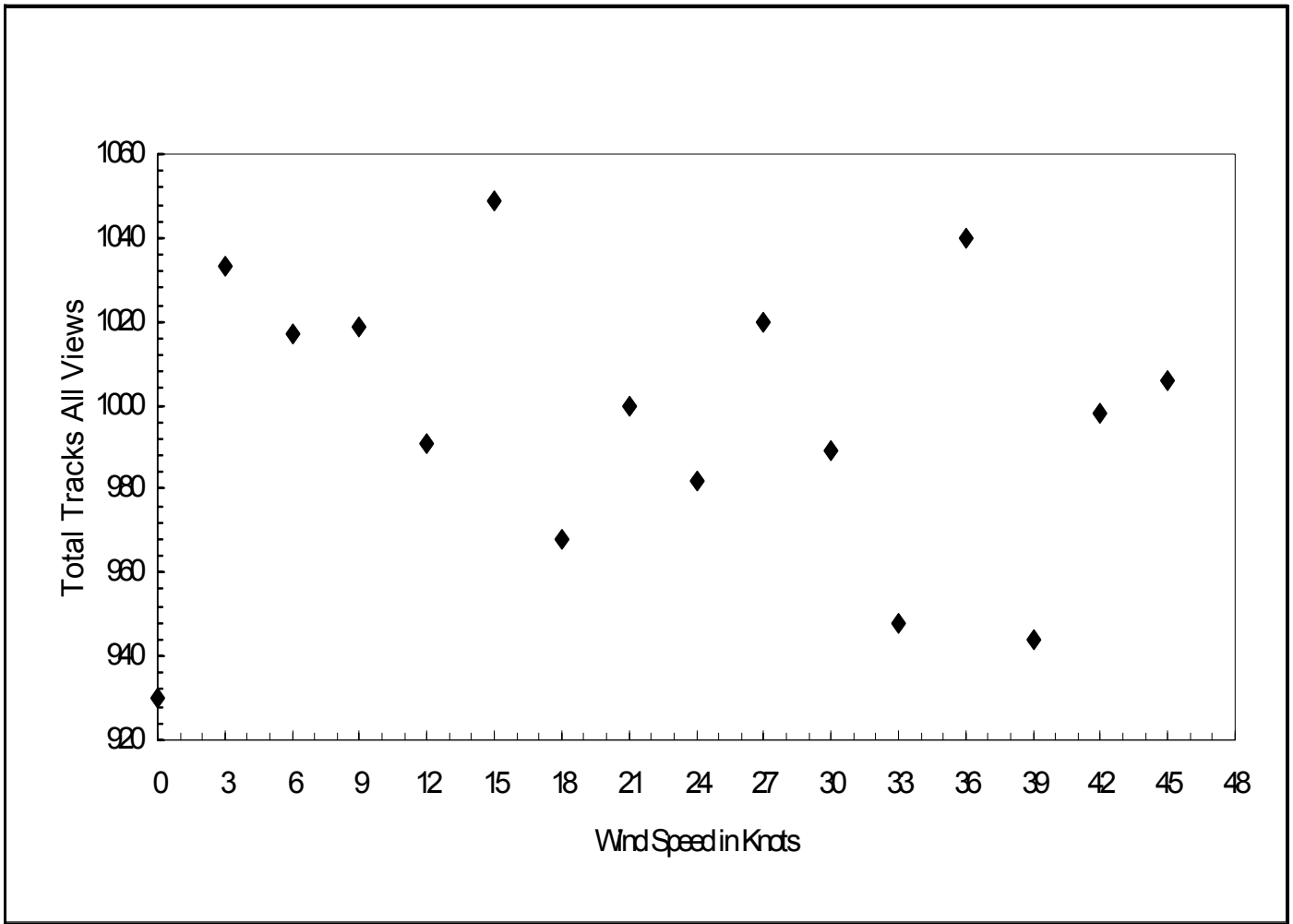
RESA Simulation

Total number of Orange Force Tracks held in all Blue Force views as a function of the cloud cover



RESA Simulation

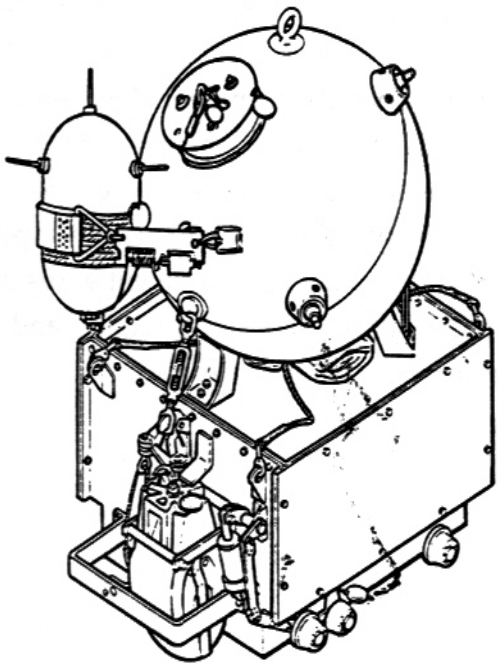
Total number of Orange Force Tracks held in all Blue Force views as a function of the



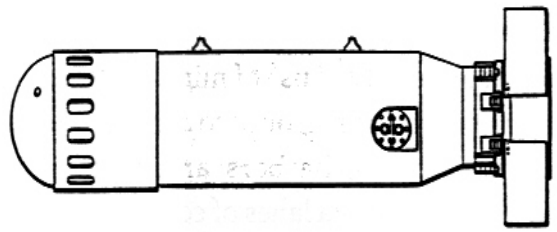
Tactical Scale Simulation
- **Tactical Decision Aid (TDA)**

- (1) Mine Countermeasure Model (MCM)
- (2) Mine Impact Burial Prediction Model

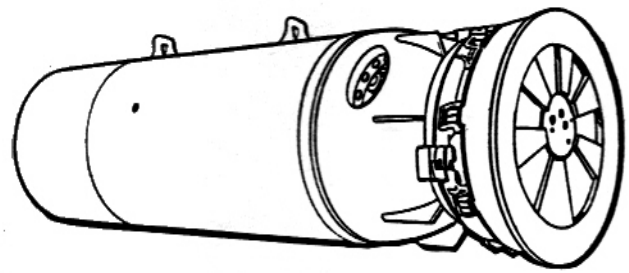
Mine Types



Moored Contact Mine
(Surface Delivered)
with Anchor and Antenna Float

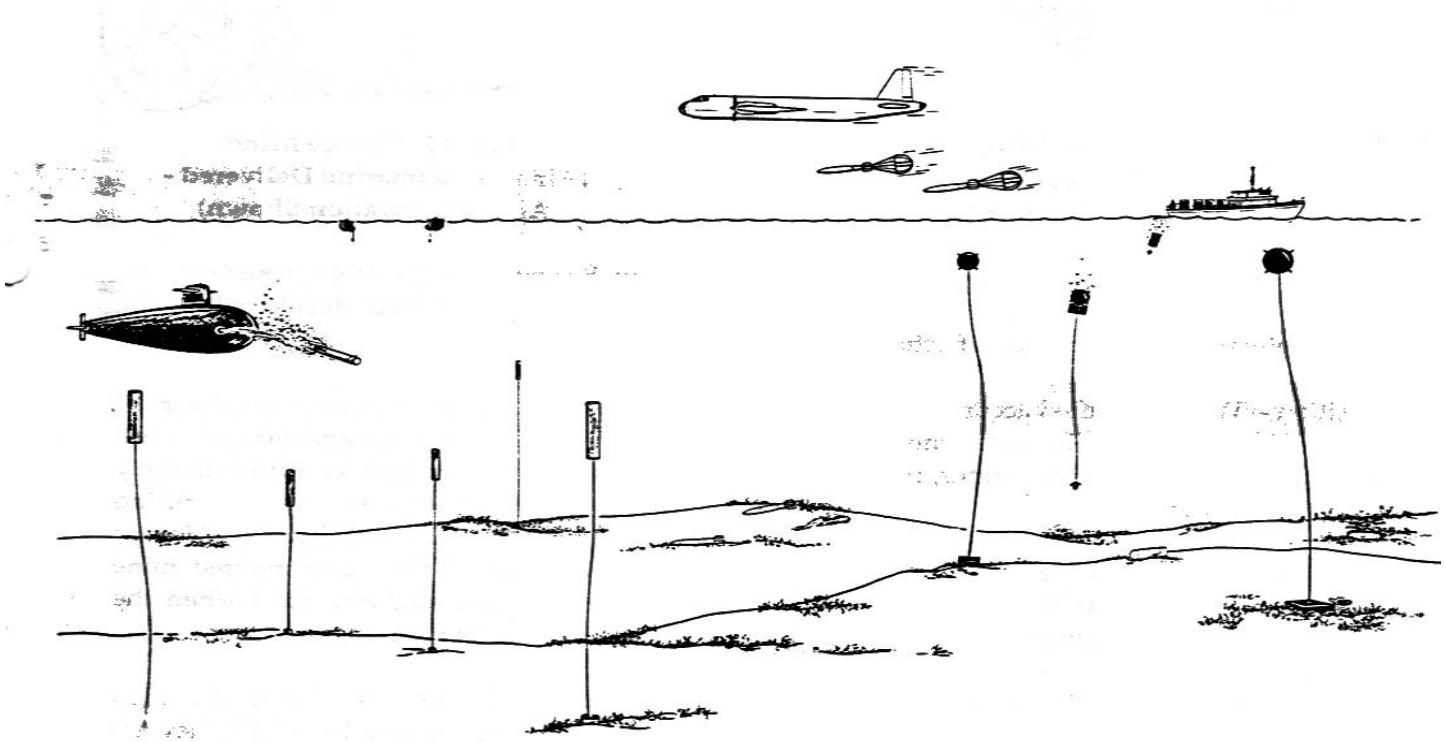


Bottom Influence Mine
(Air Delivered)



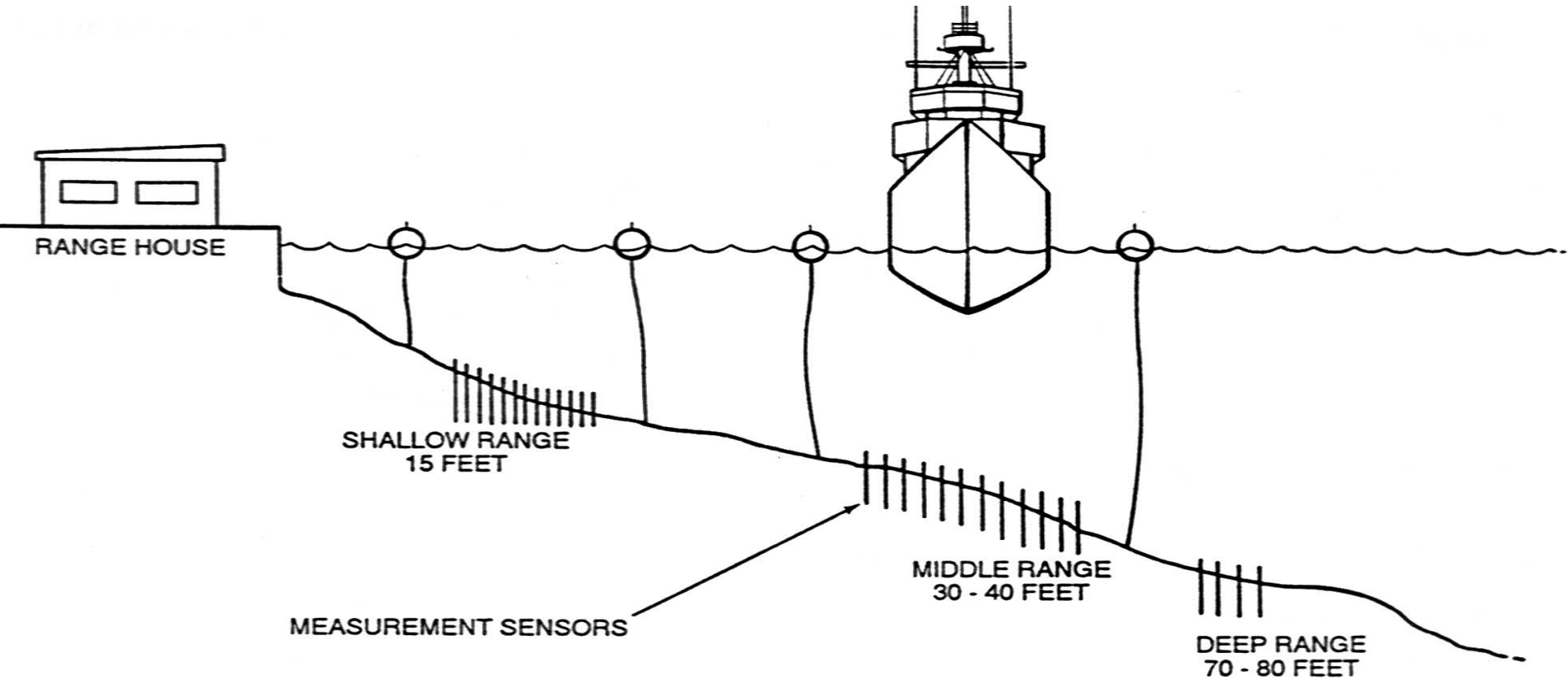
Moored Influence Mine
(Air and Submarine Delivered -
Air Configuration Shown)

Mine Sweeping



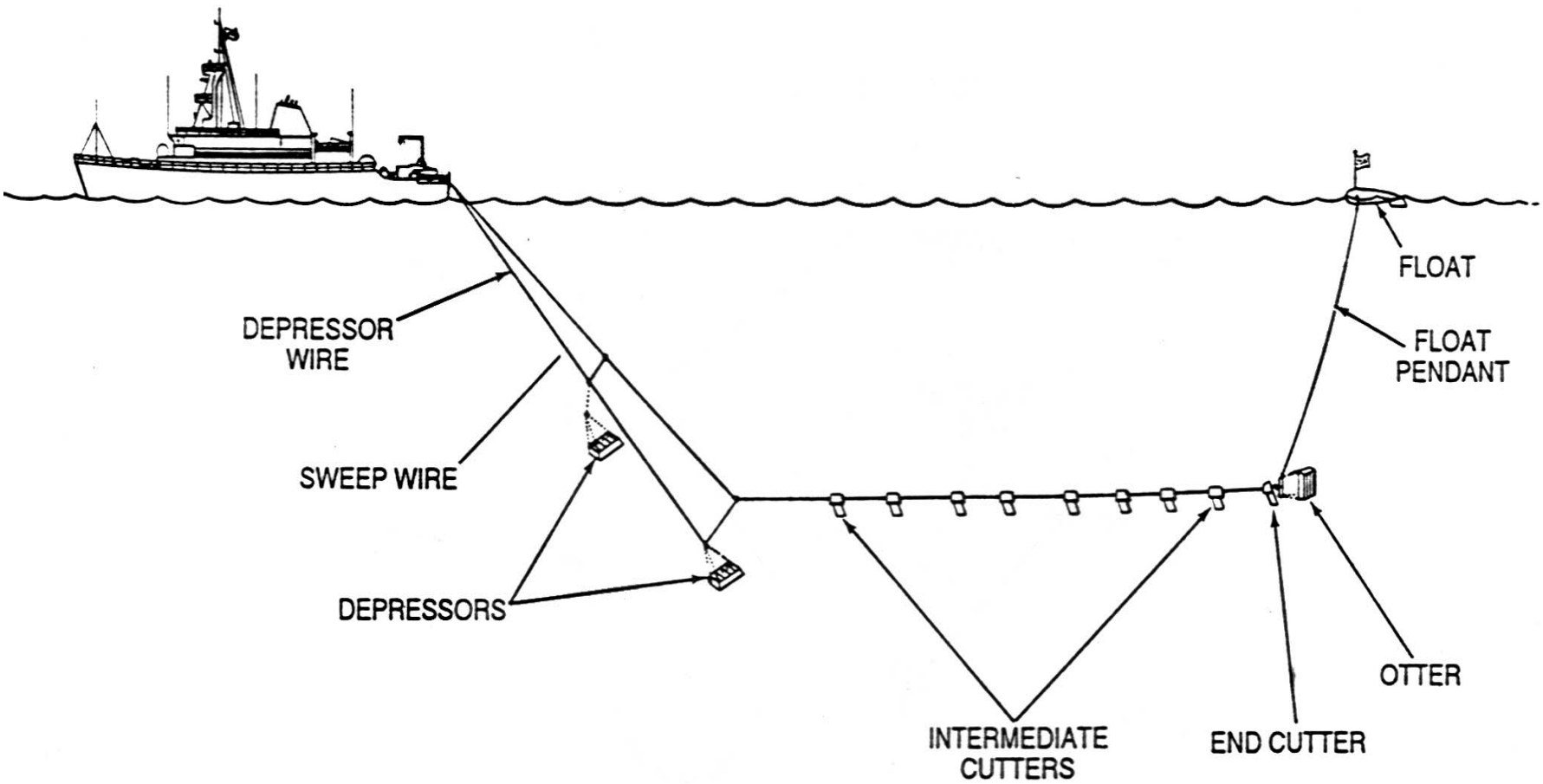
In any conflict, allied MCM Forces may be forced to defeat a wide variety of mine types.

Mine Sweeping



Magnetic Signature Measurement Range

Mine Sweeping



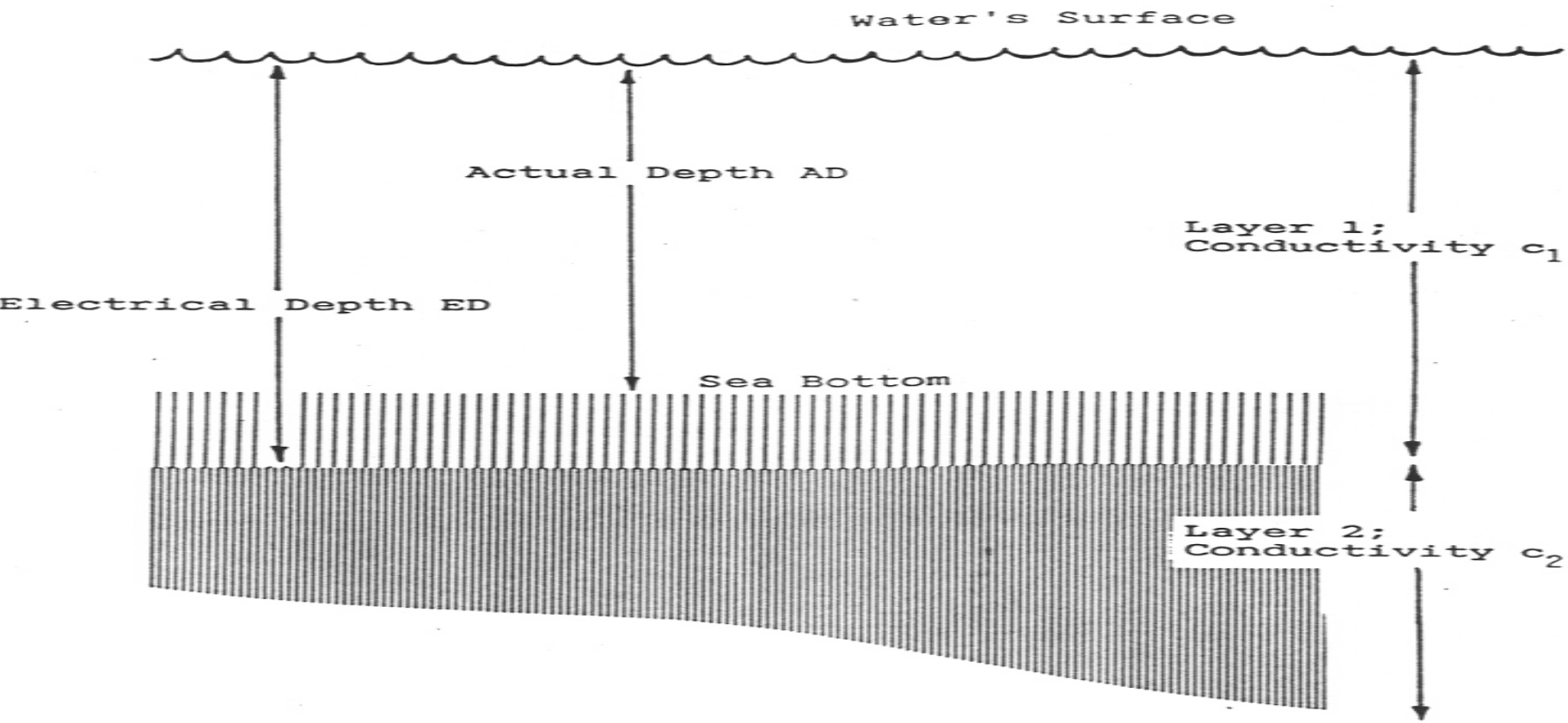
The Magnetic Minesweeping Problem

- How does natural variability effect the outputs of “METOC simple” TDAs?

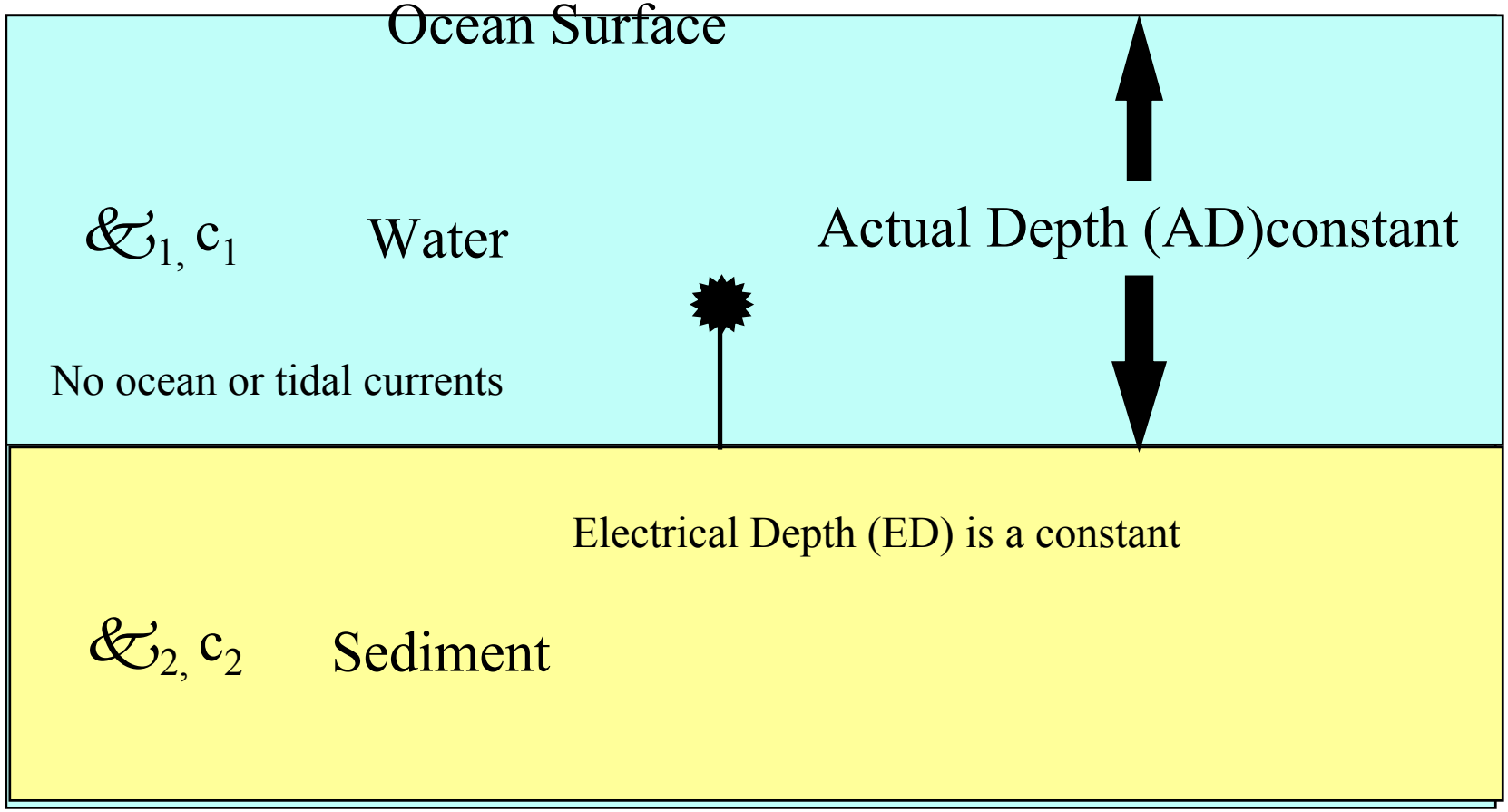
- Does there exist naturally occurring combinations of parameter variability that could cause this TDA to produce ineffective or unsafe results?

MCM Two-Layer Model

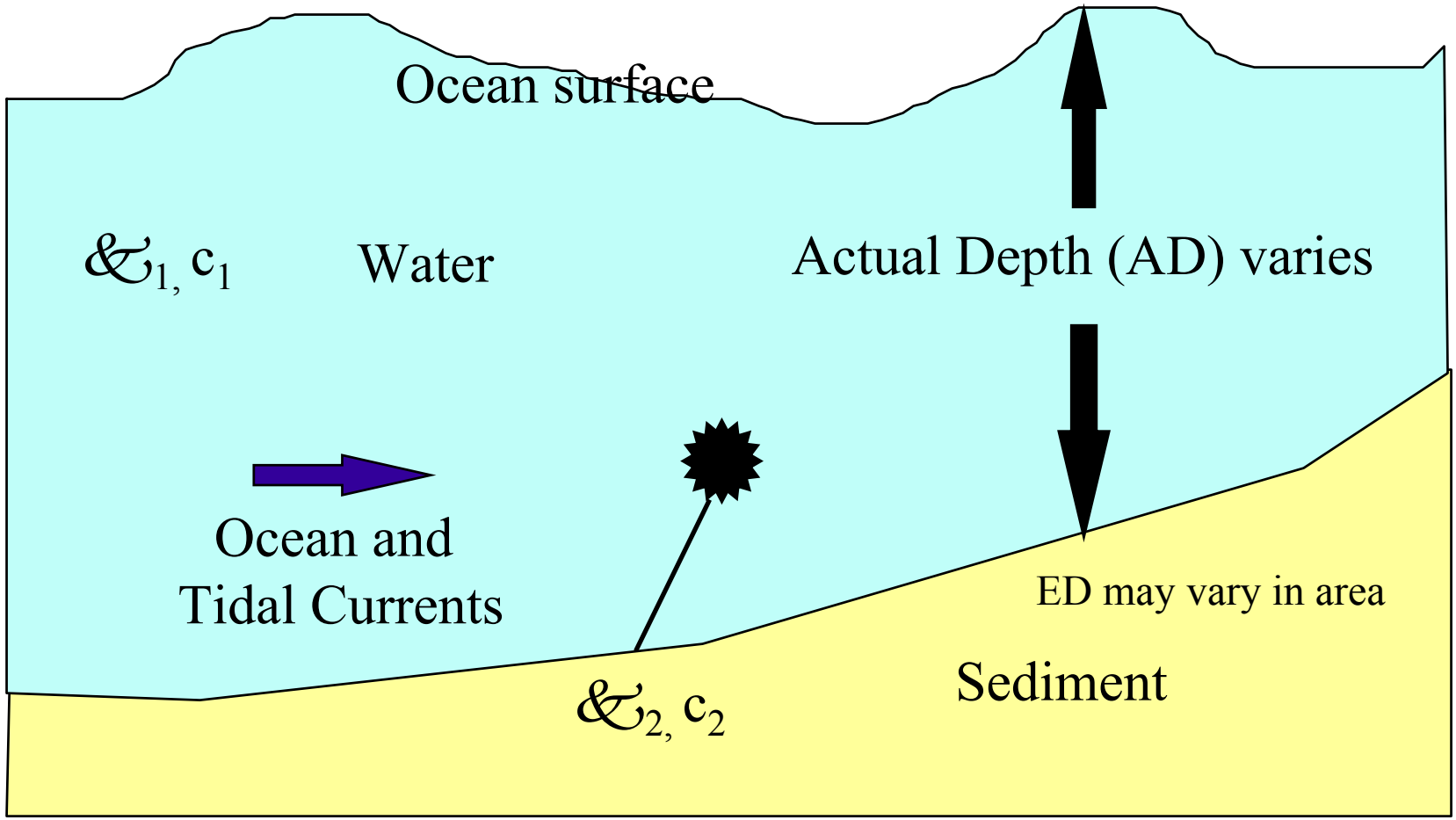
$$Q = \frac{c_1 - c_2}{c_1 + c_2}$$



Magnetic Minesweeping Model



A more realistic model



Menu1: Mine Countermeasure Vehicle (MCMV) With Sweep

- Sweep From Sweep List Submenu to Menu 1
- UDmgDist Unit of Damage Distance (1=yd, 2=m)
- DmgDist MCMV's horizontal Damage Distance
- MaxSpeed Maximum speed (kts)
- MaxRatCur Maximum rated current (kA)
- MaxGenVol Maximum generator voltage (V)
- MaxGenPow Maximum generator power (Kw)

Sweep List Submenu to Menu1

Swpid	Sweep	Configuration	Description
1	M Mk 4(m)	A	Two-boat closed-loop
2	M Mk 5(a)	A	Straight-tail two-electrode (300-yd seperation)
3	M Mk 5(a)	C	Straight-tail two-electrode (450-yd separation)
4	M Mk 6(a)	A	Diverted one side, J, 2 electrodes
5	M Mk 6(h)	A	Diverted one side, closed loop
6	M Mk 6(q)	A	Small boat, diverted one side, closed loop
7	M Mk 7(b)	A	Diverted two sides, 3 electrodes
8	M Mk 7(b)	B	Diverted two sides, 3 electrodes
9	M Mk 7(d)	A	Small boat, diverted two sides, closed loop
10	M Mk 7(d)	B	Small boat, diverted two sides, closed loop

Menu 2: MCMV'S Measured Magnetic Field

- UCodeDepth — Unit of CodeDepth (2=m, 3=ft)
- CodeDepth — Depth corresponding to Hz_mcmv and Hz_gen
- Uhz — Unit of Hz_mcmv and Hz_gen (1=nT, 2=mG, 3=gam)
- Hz_mcmv — MCMV's constant field, z component
- Hz_gen — Generator stray field per kA, z component

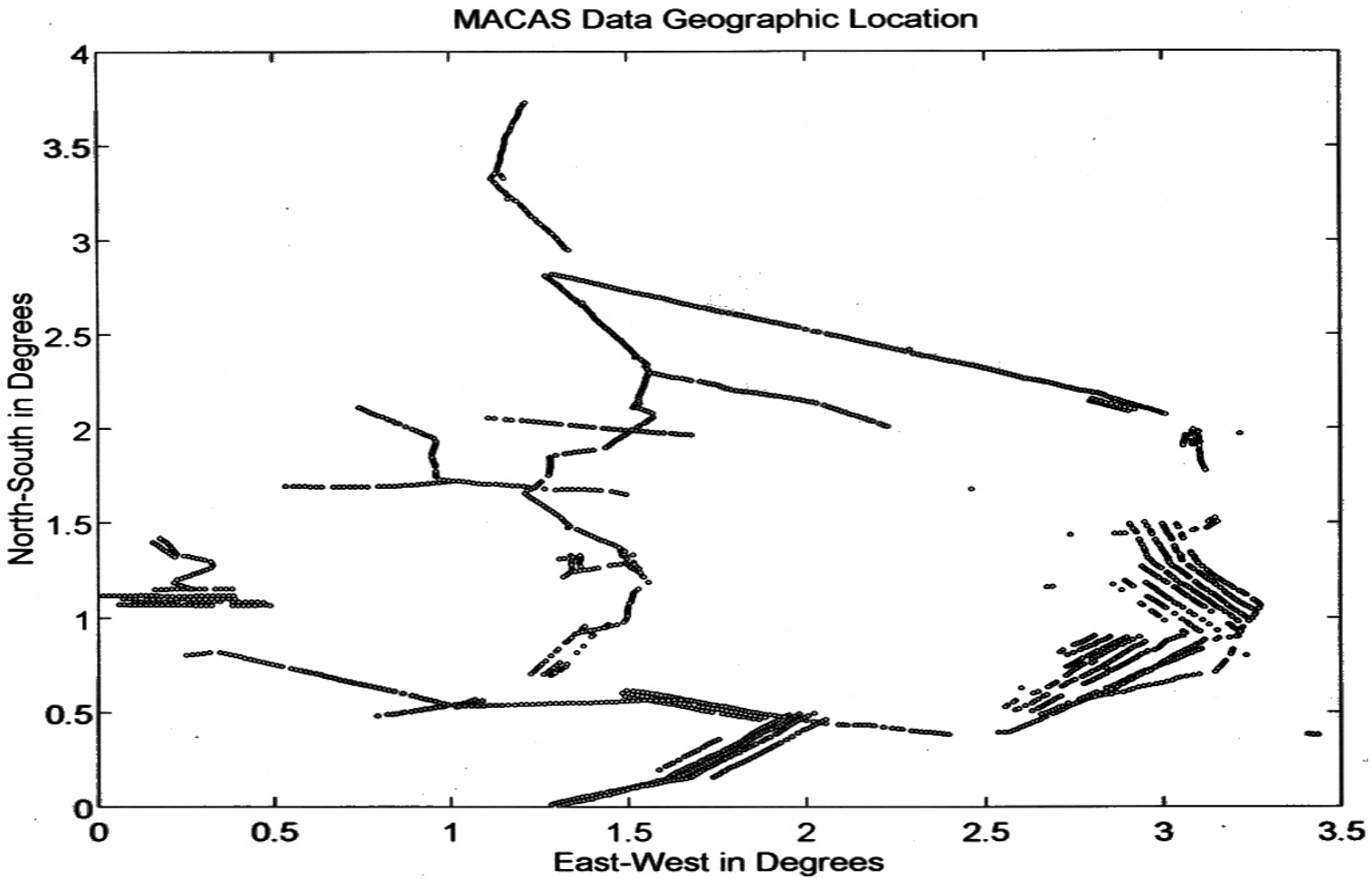
Menu 3:Mine's Characteristics

- MineType 1=Ground, 2=Moored
- FldComp Magnetic field component (1=hor, 2=ver, 3=tot)
- UHm Unit of Hm (1=nT, 2=mG, 3=gam)
- Hm Threshold actuation level
- Tm Threshold stretch interval (sec)

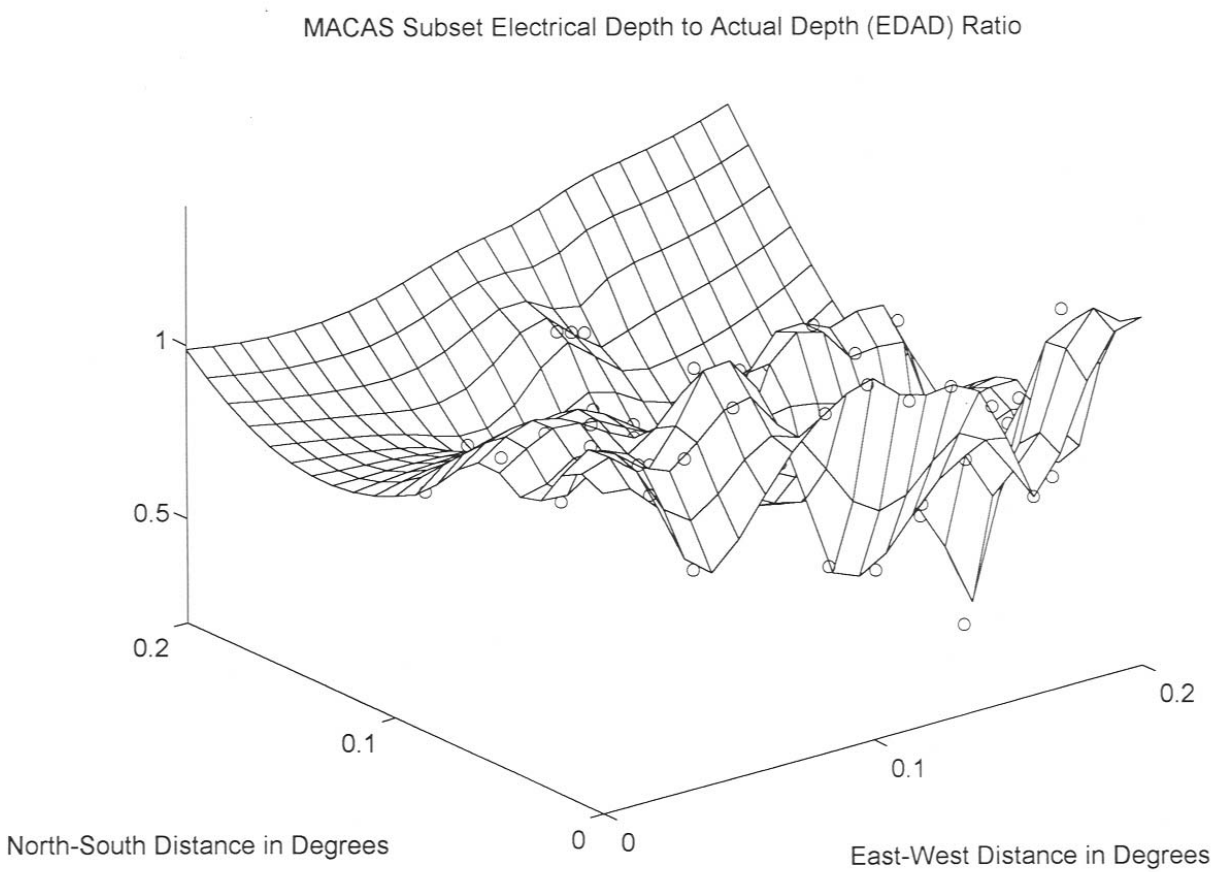
Enivironment

- Udepth — Unit of depth (2=m, 3=ft, 5=fm)
- CaseDepth — Mine case depth
- AD — Actual depth of the sea bottom
- Q — Reflection coefficient
- ED/AD — Electrical Depth/Actual Depth
- UWatCon — Unit of WatCon (1=mmho/cm, 2=mho/m)
- WatCon — Water conductivity

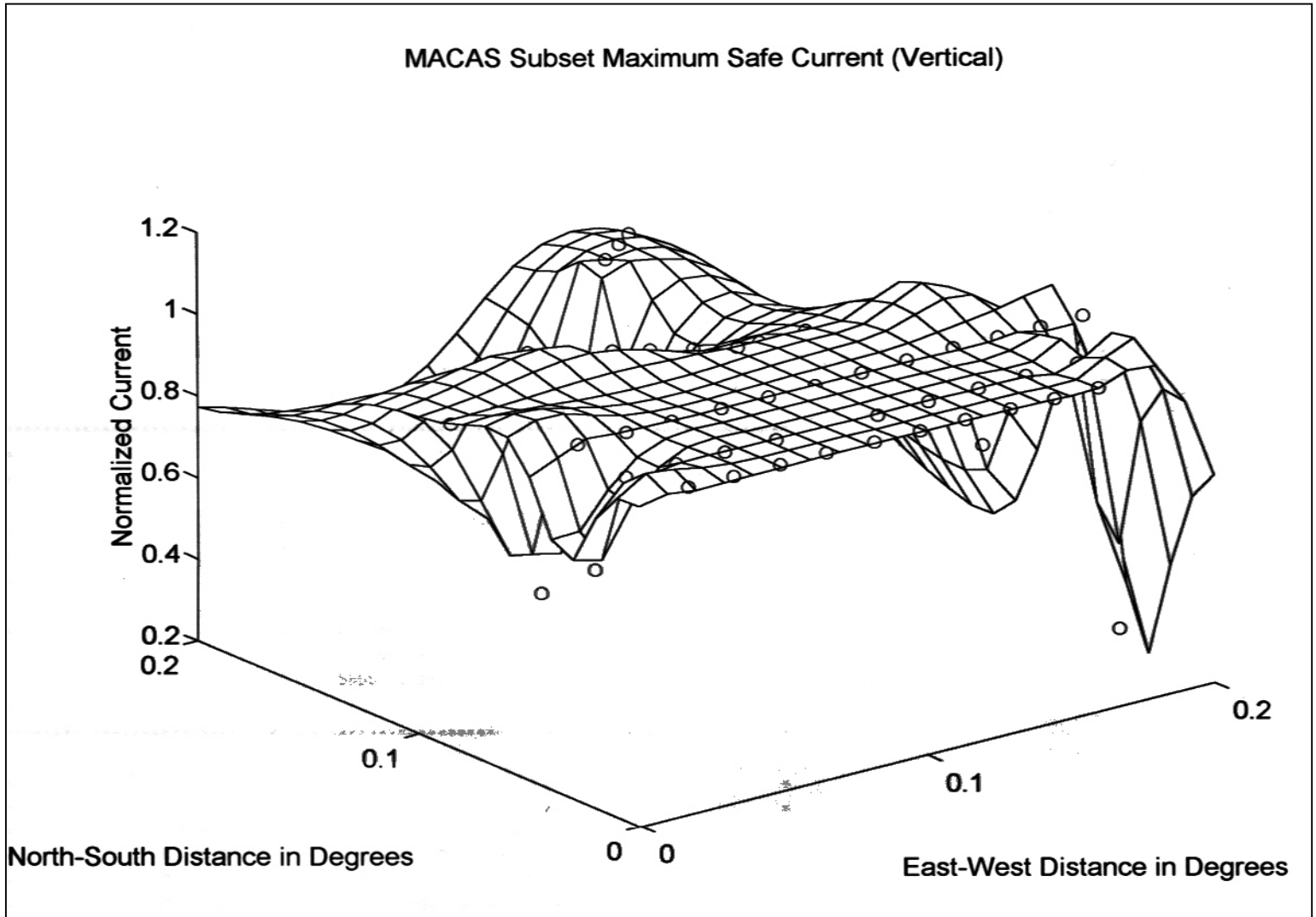
Naval Oceanographic Office's MACAS Data



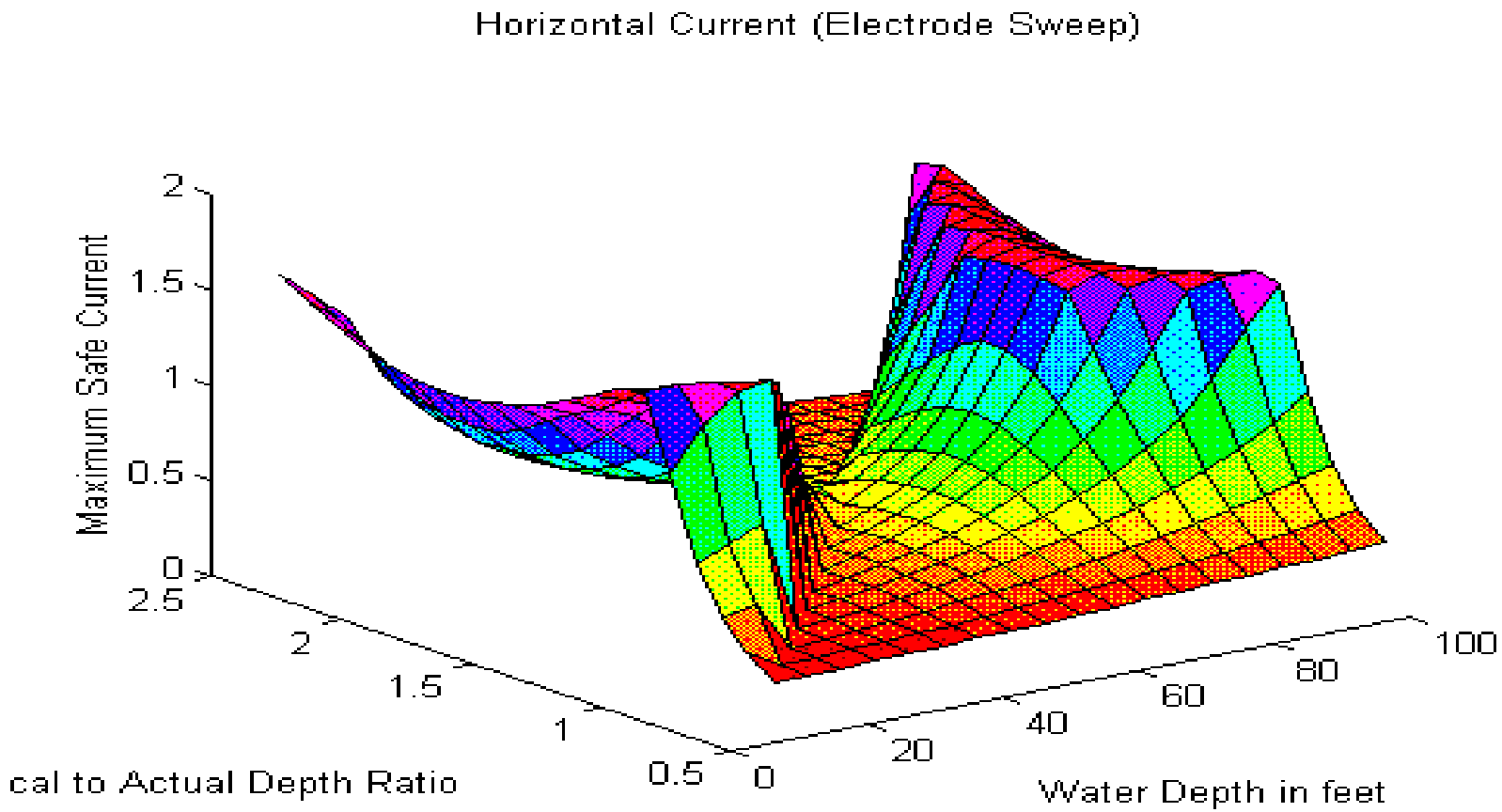
ED/AD Ratio


MACAS Subset Electrical Depth to Actual Depth (EDAD) Ratio
1
0.5
0.2
0.1
0
0
0.1
0.2
North-South Distance in Degrees
East-West Distance in Degrees

Maximum Safe Current



Variation in safe electrical current levels with respect to actual water depth and electrical depth to actual depth ratio.



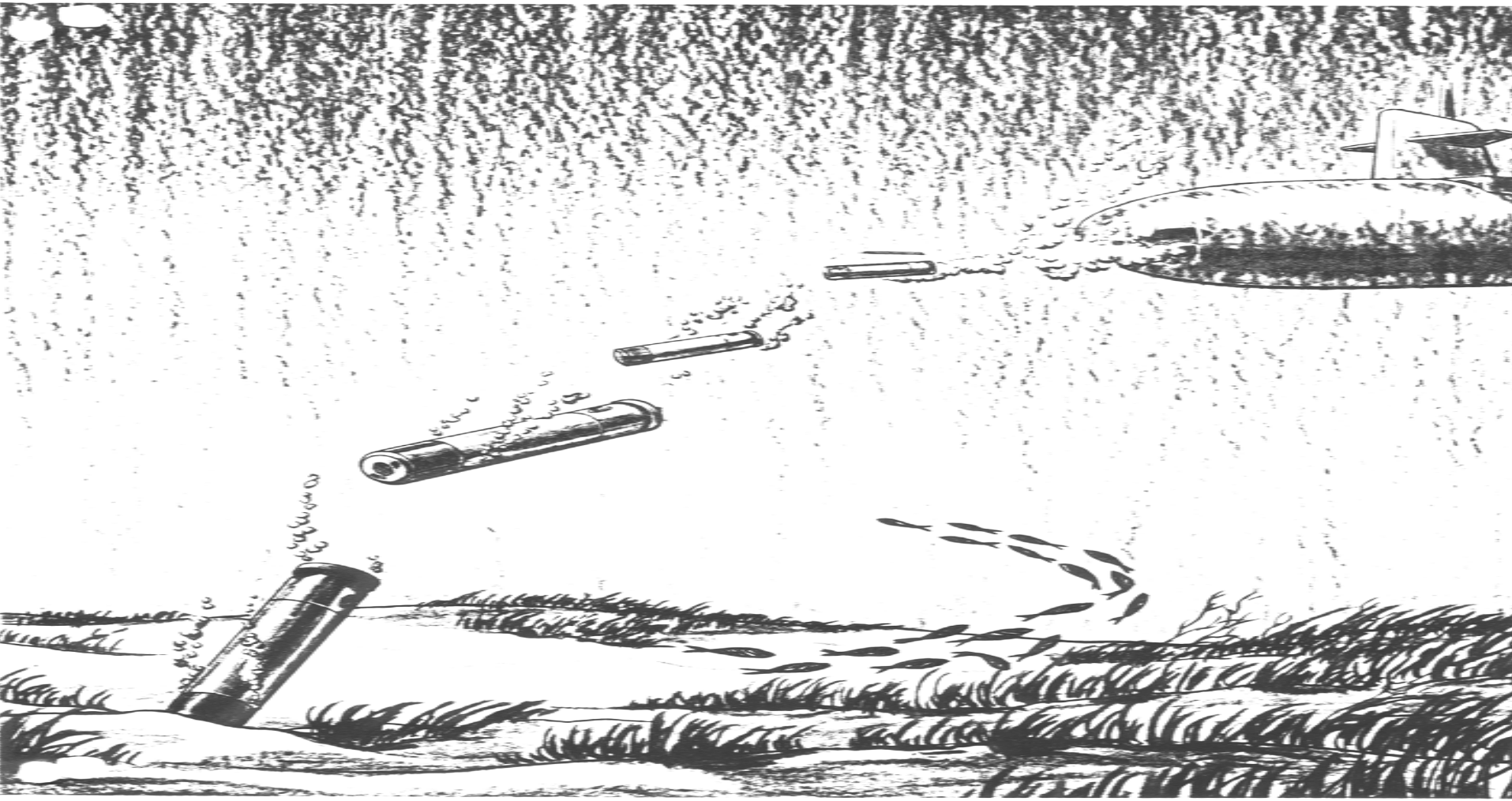
Notice that safe current levels calculated at 60-100 ft depths
are unsafe at some shallower depths, but safe again at depths less than 30ft
for reasonable ED/AD values.

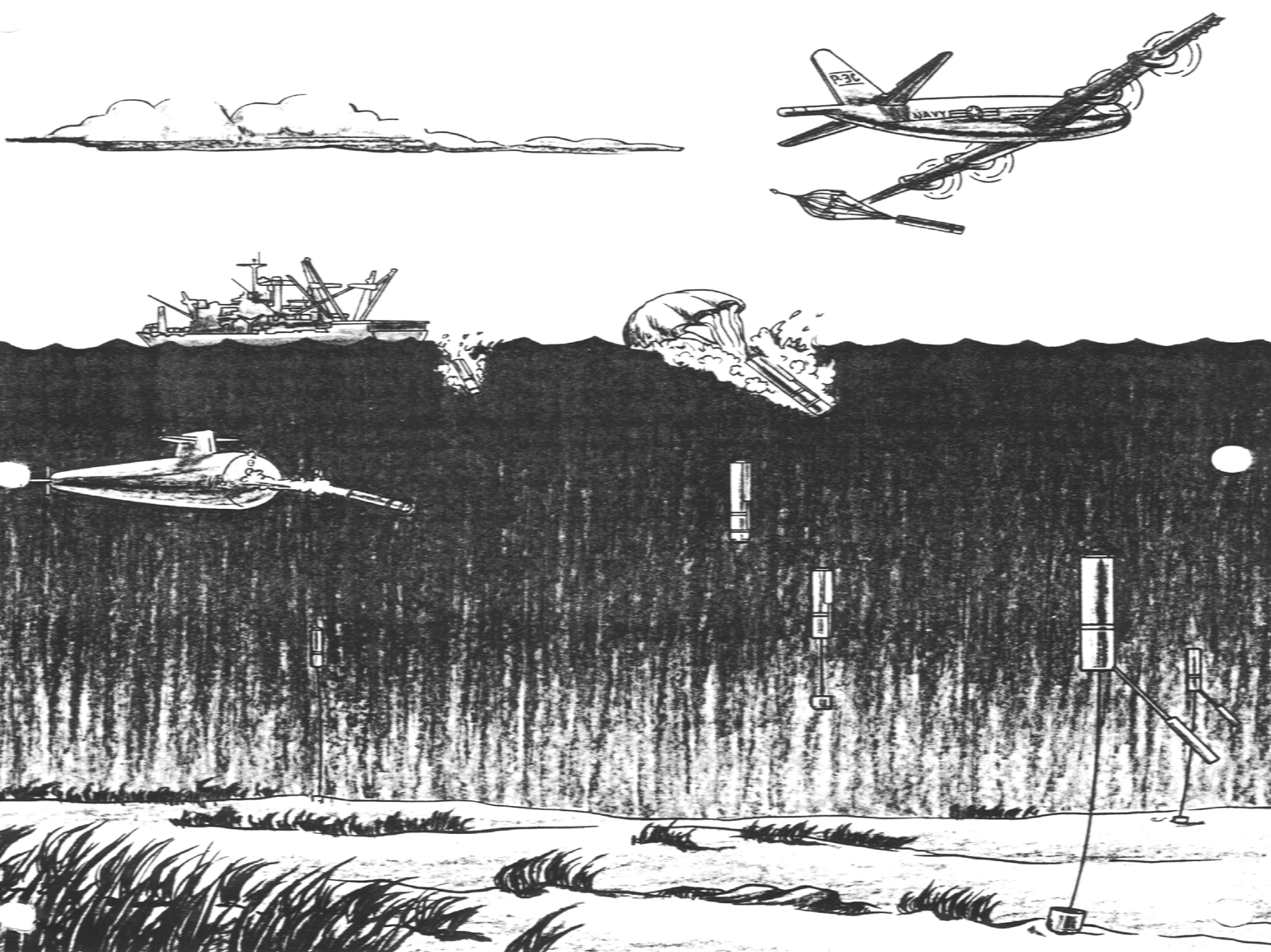
Environmental Effect in Magnetic Mine Sweeping

- Assuming single METOC value input for the TDA and applying the results over an area as small as a few nautical miles would lead a MCMV into a dangerous situation where local maximum safe current value are exceeded.

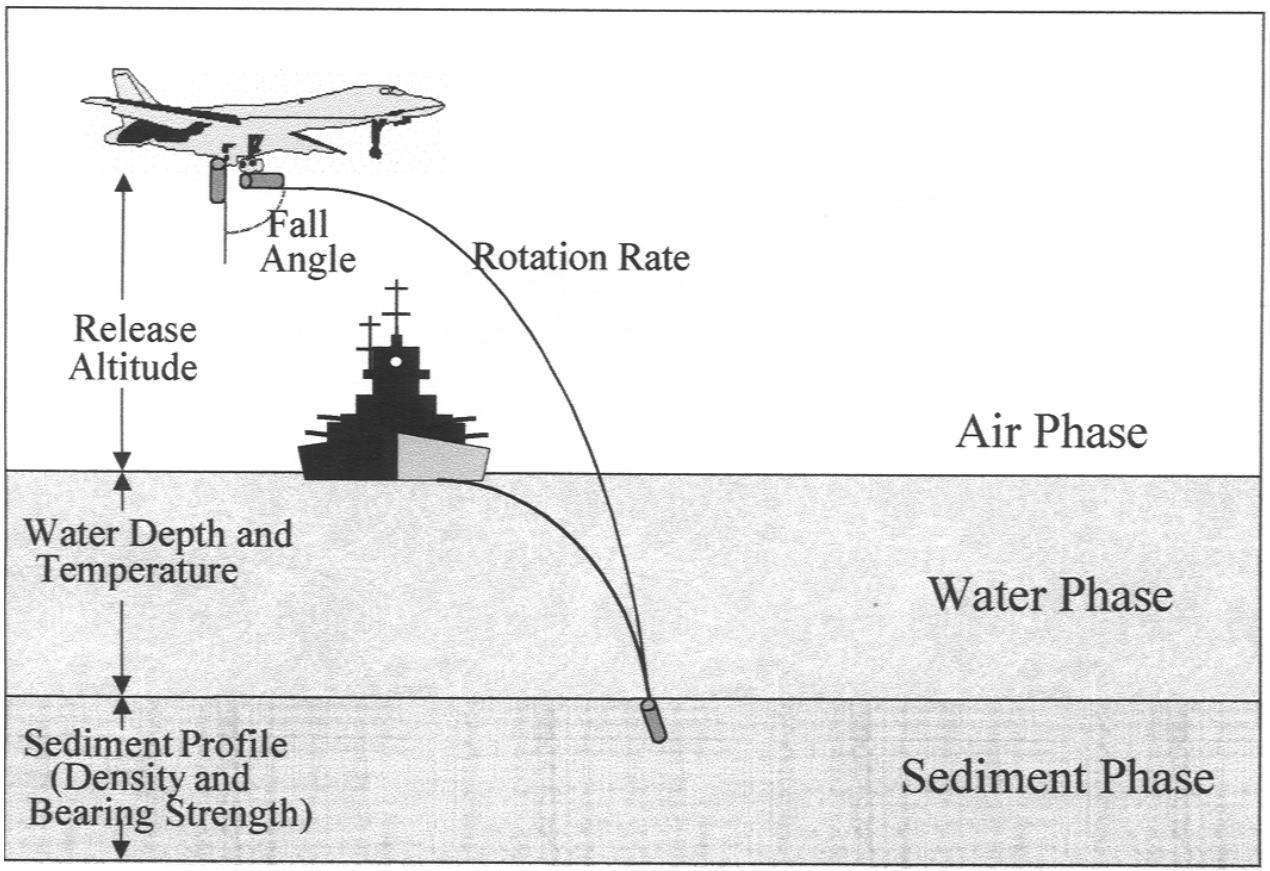
Mine Impact Burial Prediction

Mine Burial by Submarines




P-3C
NAVY

Mine Impact Burial



Purpose of the Study

- Identification of the Key Environmental Factors for the Mine Impact Burial
- Establishment of the Synthetic Environmental Component in the Mine Impact Burial Model

Mine Impact Burial Model

- Arnone & Bowen Model (1980)
- Modified Impact Burial Model (Satkowiak 1987, 1988)
- IMPACT25 (Hurst, 1992)

Arnone-Bowen Model

- One dimensional dynamics of falling cylinder (vertical)
- Three prescribed media - the air, water, and sediment
- Forces on the cylinder
- Two “cavity” phases
- Sediment treated as a fluid
  - Sediment density and shear strength

Modified Impact Burial Model (Satkowiak, 1987)

- Projected area - the area of the cylinder impacting the bottom
- Added mass - apparent mass due to the buoyancy force (small effect)
- Drag calculation (effect of water temperature)
- Sediment treated as a fluid
  - Sediment density and shear strength

IMPACT25

(Hurst 1992)

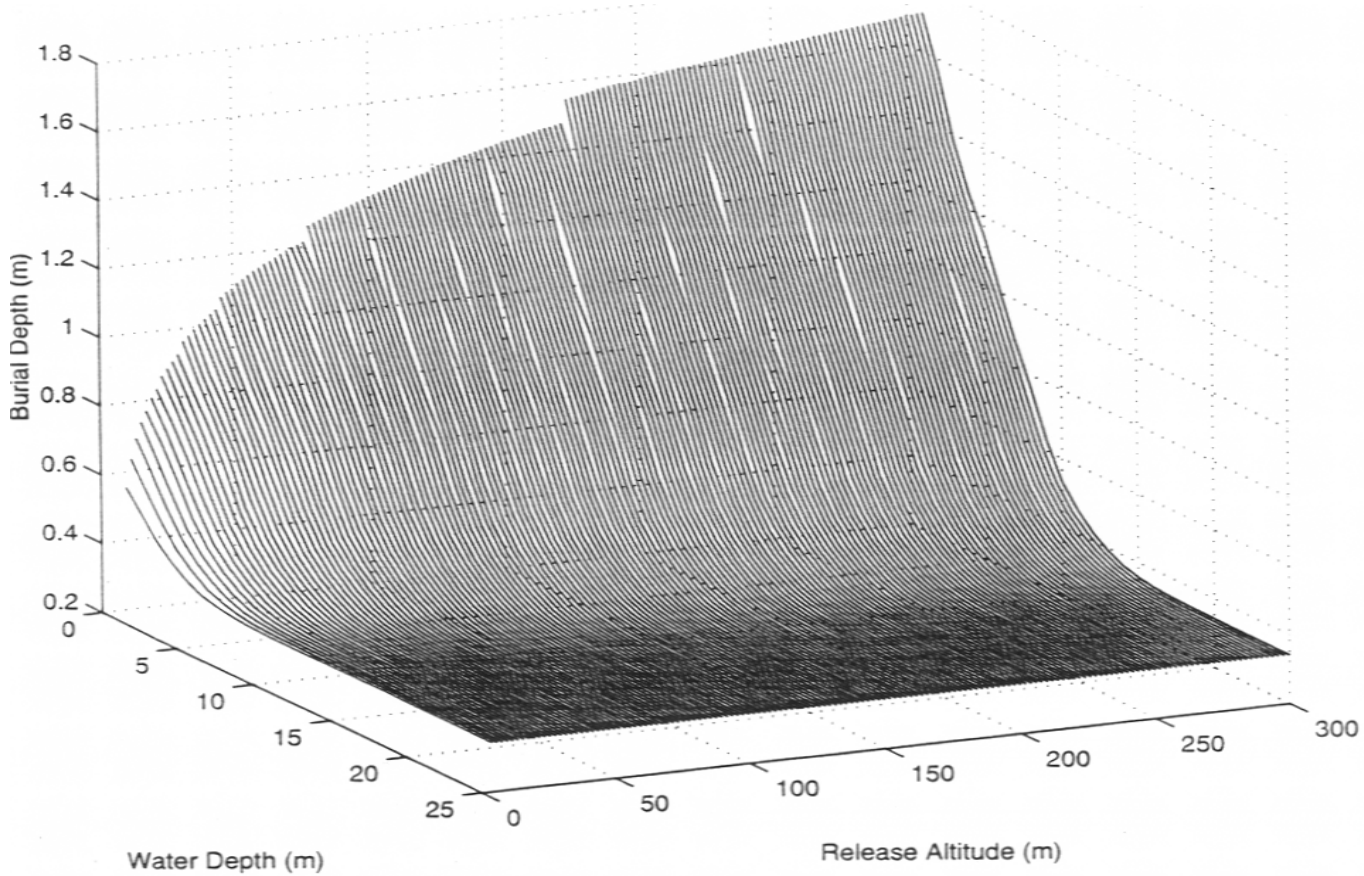
- Two dimensional - vertical & horizontal
- Tumbling about the horizontal axis
- Multi-layer sediments
- Sediment treated as a solid that undergoes plastic deformation
  - Sediment density and bearing strength

Statistical Relation for Clay Beds

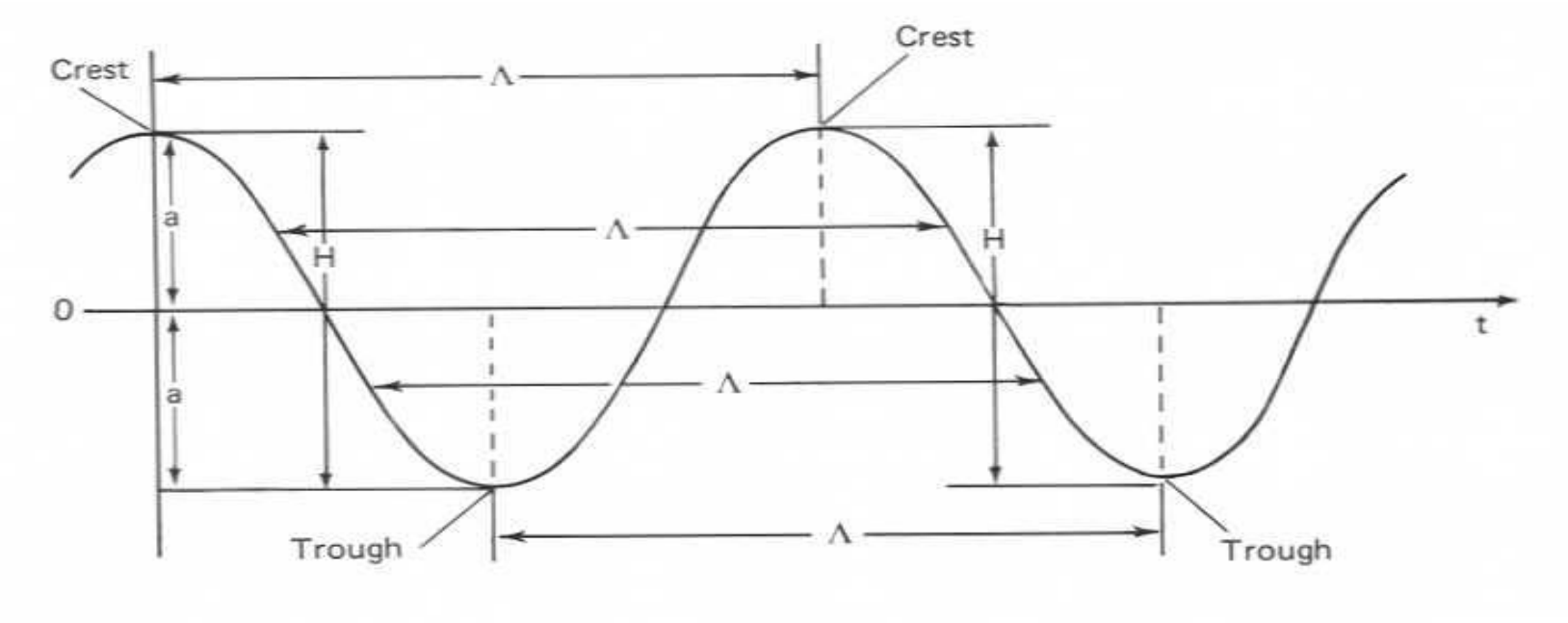
- Correlation between the bed density and shear strength

- $S = \not{\rho}^{\alpha}$ (Krone 1963)

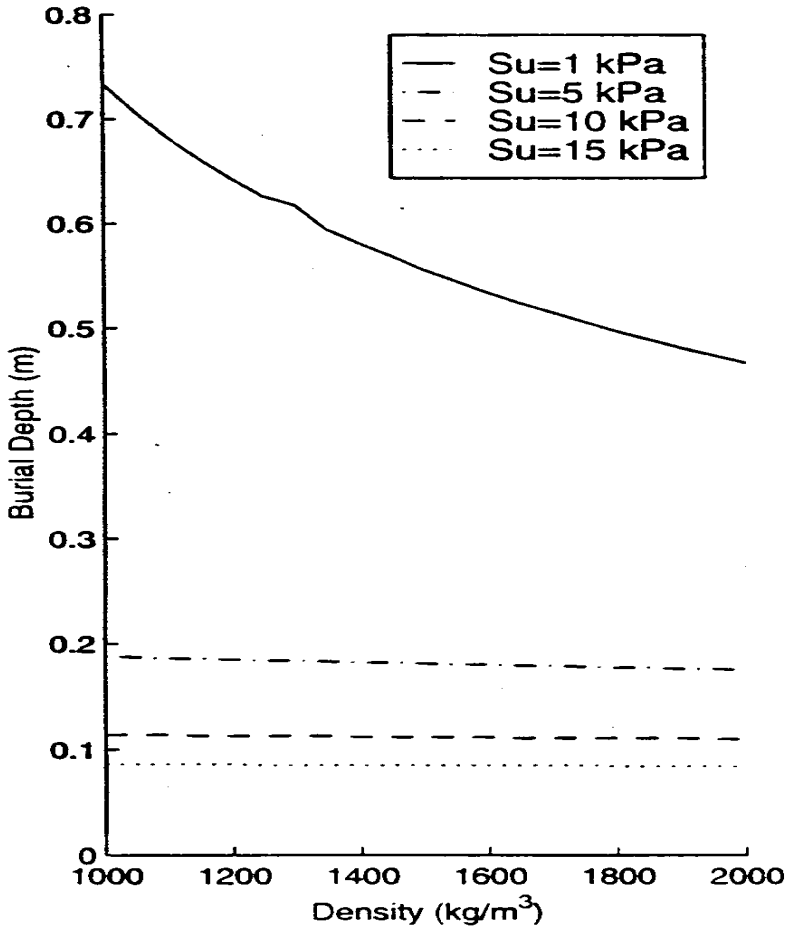
Burial Depth Versus Release Altitude and Water Depth

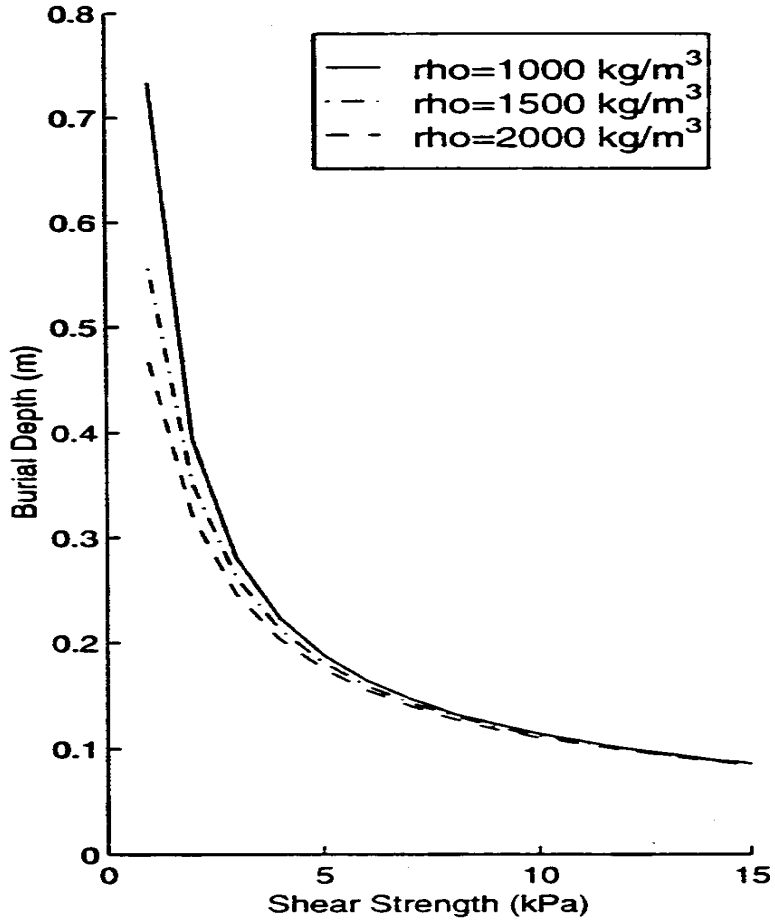


Ocean Waves



Effect of Sedimentation on Mine Burial





Recommendations

- Small effect of water temperature on drag.
- Sediment - the key component in the mine impact burial
- Measurements on burial depth, sediment density, bearing strength (urgent)
- Future improvement of IMPACT25 through including dynamics of water and sediment phases rather than prescribing them

Current Improvement of IMPACT25

- Falling Cylinder in a Varying Water and Sediment Phases (Waves, Sand Waves, Sediment Transport, etc..)
- Observational Data Set of Burial Depth, Sediment Density, and Shear Strength
- Mine Burial Experiment

New Development

- A new course Modeling & Simulation in Ocean Environment (MV4030) was developed.
- A new ONR research program (Mine Impact Burial Prediction) was initiated recently.